Nationwide Differential Global Positioning System

Federal Railroad Administration

Leonard W. Allen III

Program Manager

Intelligent Railroad Systems

Office of Research and Development

Federal Railroad Administration

Presented to:

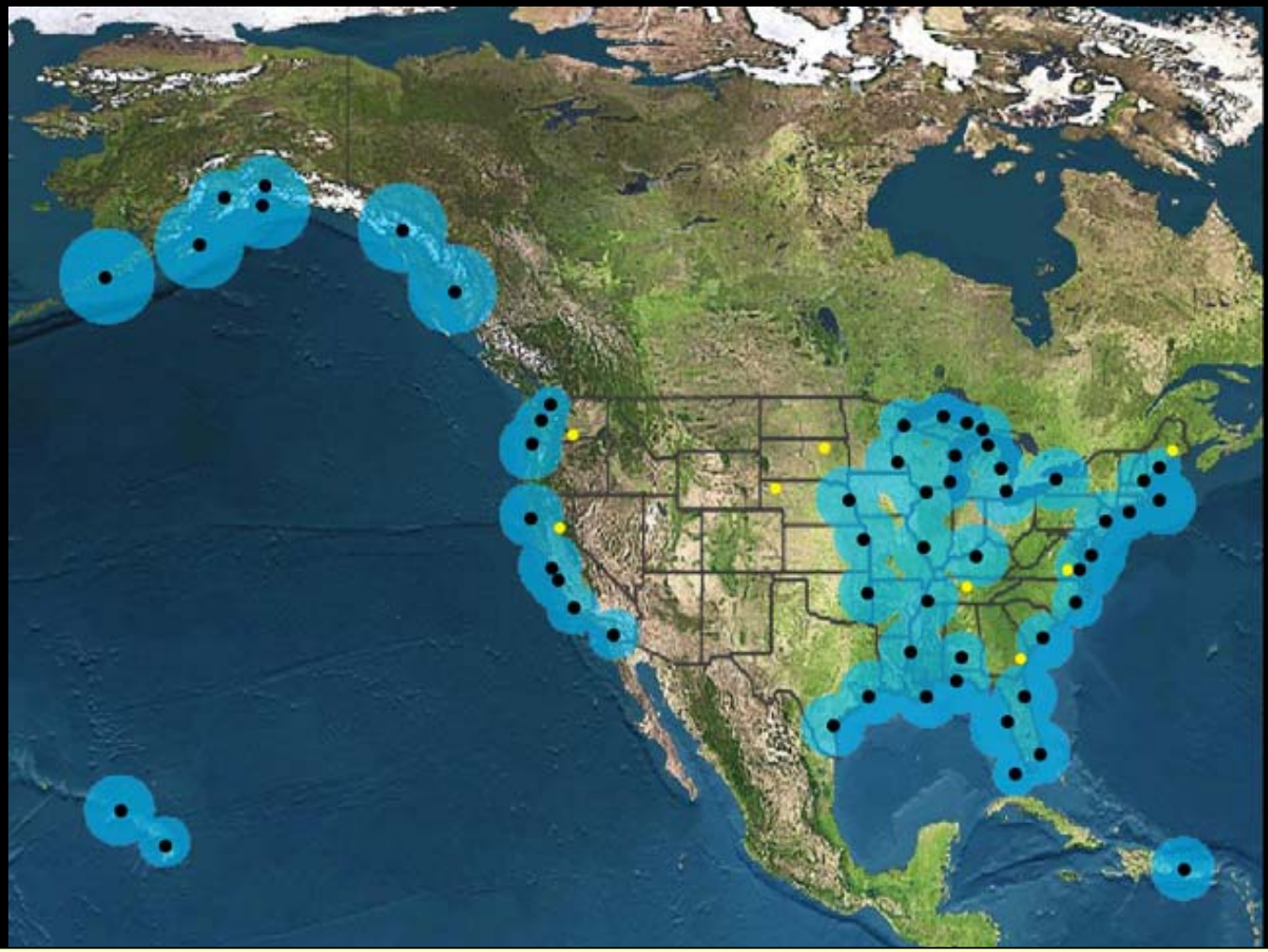
National Transportation Research Board's Positive Train Control Symposium

March 3, 2005

Differential GPS (DGPS)

Federal Railroad Administration

Reference Station



The Coast Guard developed the DGPS service to provide the high accuracy needed for harbor and river navigation.

Interagency Team
Evaluated Several Differential GPS Options

Federal Railroad Administration

- **Plans to expand the system into a nationwide service began in January 1997**
  - **Executive Steering Group (Council)**
  - **Policy & Implementation Team**

Participants

DOT/OST	**Department of Commerce**
U.S. Coast Guard	**Department of Interior**
Federal Highways Administration	**Department of Agriculture**
Federal Railroad Administration	**Army Corps of Engineers**
Federal Aviation Administration	**U.S. Air Force**
Environmental Protection Agency	**Various States**

Public Law 105-66
Section 346
October 27, 1997

Federal Railroad Administration

- Authorized the creation of the NDGPS and provided initial funding
- Reuse Air Force Ground Wave Emergency Network (GWEN) Equipment and Sites to augment installation of NDGPS
- Integrate Coast Guard's DGPS into NDGPS
- Provide GPS data to the National Geodetic Survey's Continuously Operated Reference Stations (CORS) service for surveying applications
- Investigate improves to allow the reference stations to provide water vapor information to the National Oceanic and Atmospheric Administration's weather modeling
- Ensure that the service is provided free of any user fees
- Continually upgrade the system to meet the users needs
- Sponsor new applications

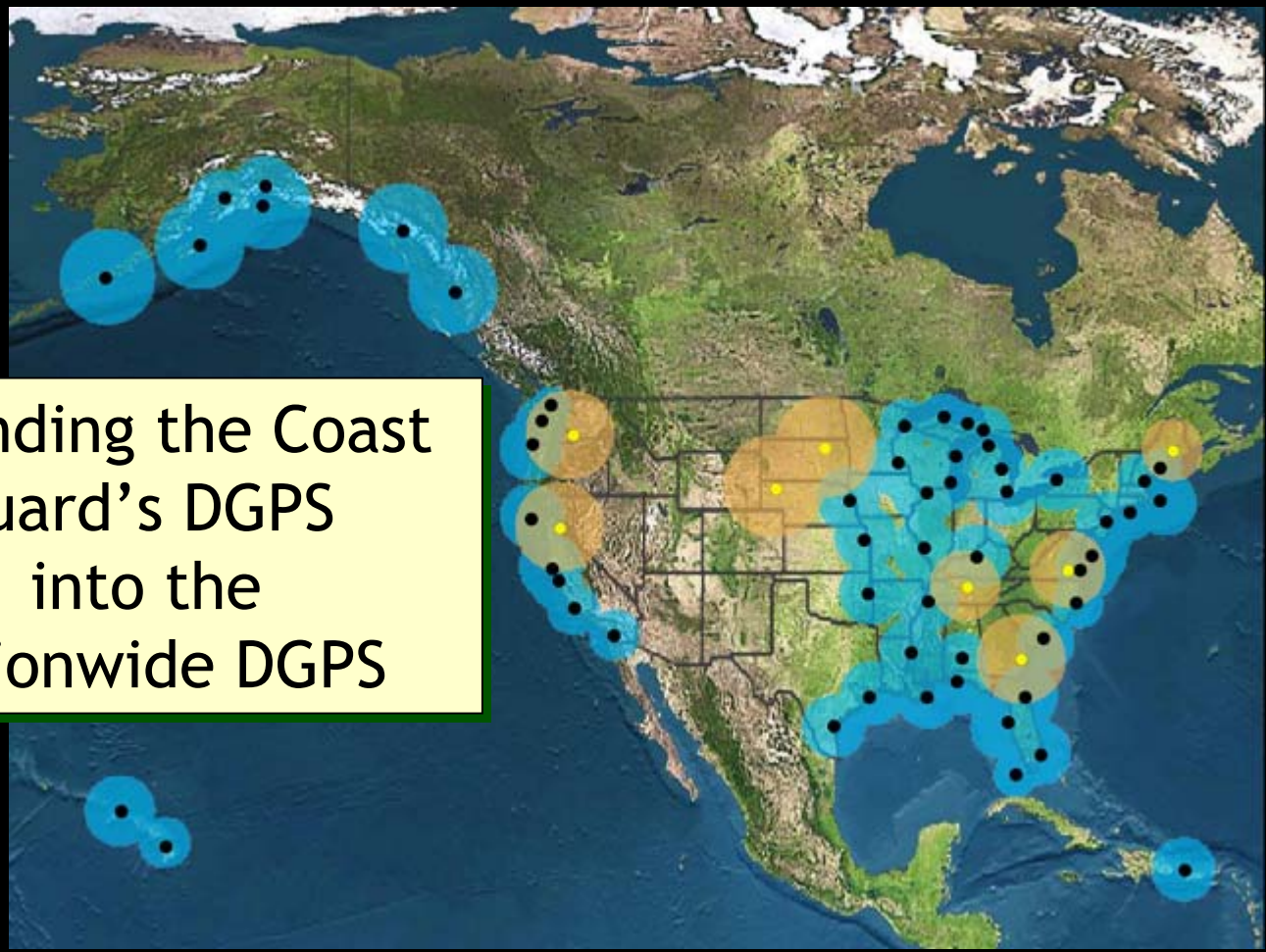
Air Force Ground Wave Emergency Network (GWEN)

The GWEN Opportunity

Federal Railroad Administration

Transferred 46 of the Air Force GWEN sites to the Coast Guard, saving the Air Force approximately $6.8M in decommissioning costs and saving the NDGPS program about $30M in construction costs. We also transferred all of the Air Force's spare parts, transmitters and generators.

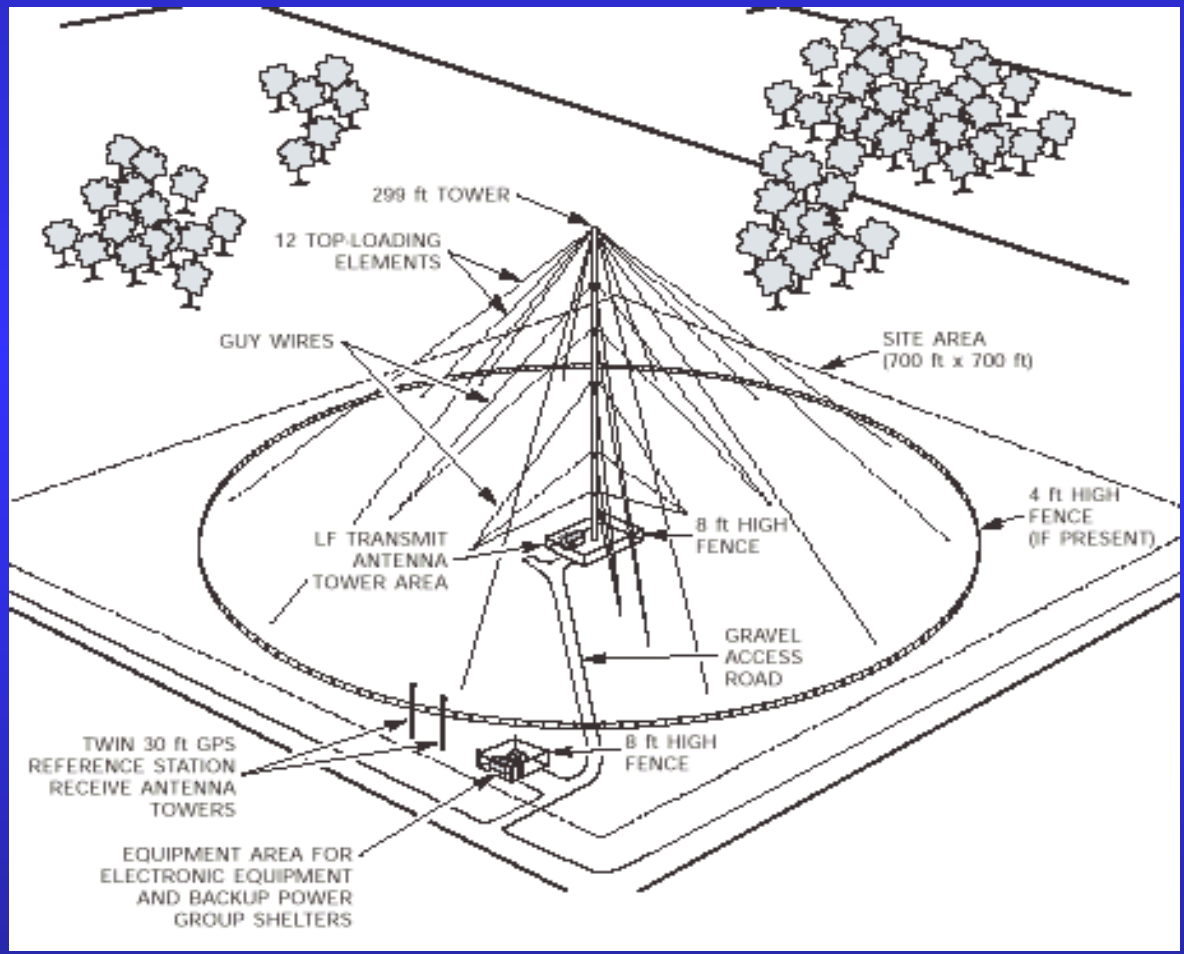
Nationwide Differential Global Positioning System



Expanding the Coast Guard's DGPS into the Nationwide DGPS

NDGPS Reference Station

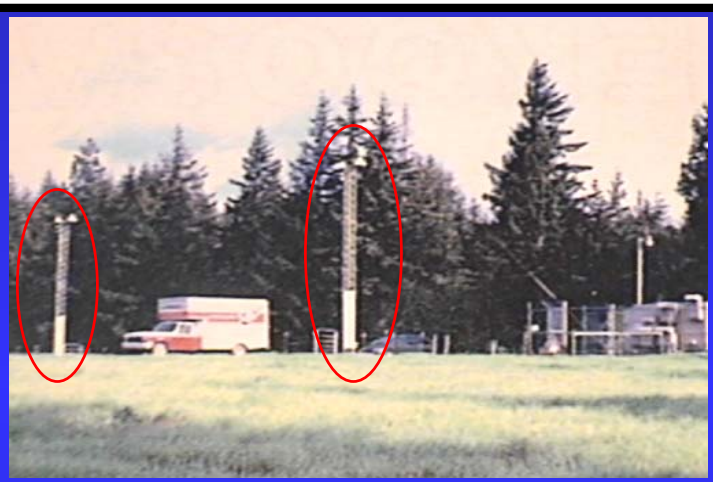
Federal Railroad Administration



Converted GWEN to NDGPS

Appleton, WA

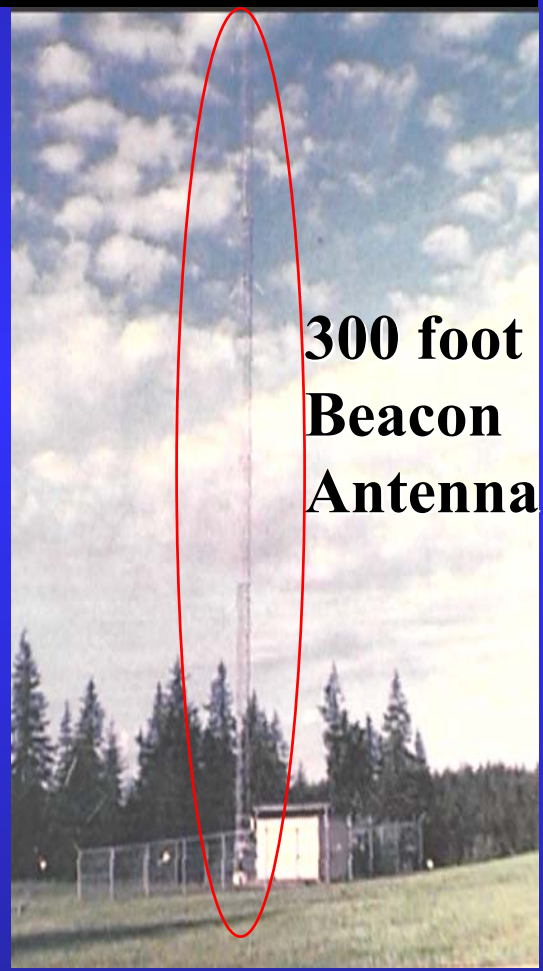
Federal Railroad Administration



Reference & Integrity Antennas
Two sets of each

DGPS Equipment Shelter

There is a similar shelter for the 25KW generator



300 foot Beacon Antenna

NDGPS Reference Station Equipment

Federal Railroad Administration

Fully redundant equipment for improved operational availability

- 99.7% for single coverage
- 99.9991% for dual coverage

NDGPS Success Through Teamwork

Army Corps of Engineers

Department Of Transportation
Federal Highway Administration

Department Of Transportation
Federal Railroad Administration

Department of Interior
Bureau of Land Management

Federal and State Cooperation

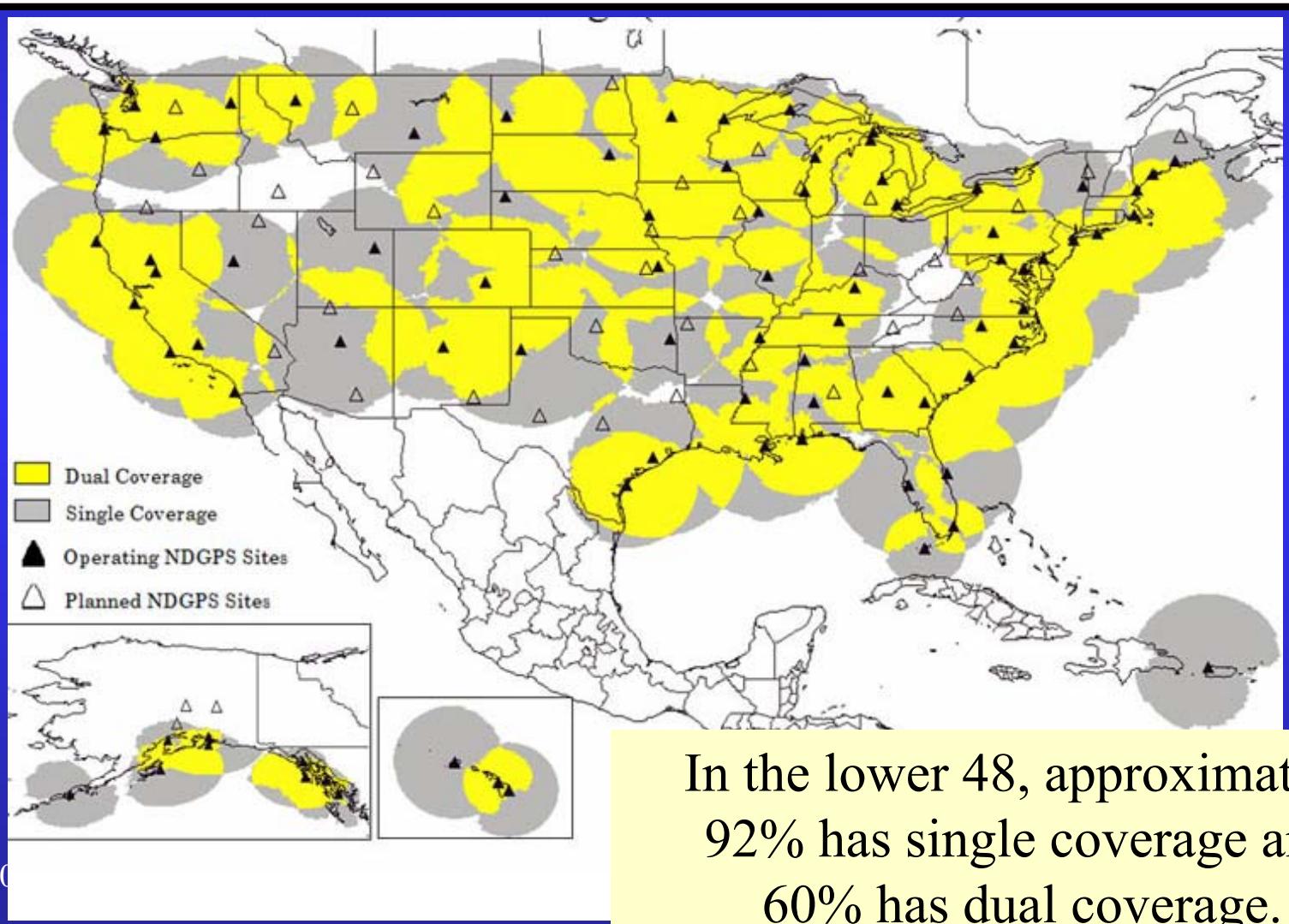
Federal Railroad Administration

In addition to the nine federal agencies that have cooperated in the development of NDGPS the following states have made significant contributions, in terms of land for sites and funding to build sites:

Idaho	North Dakota	Virginia
Minnesota	Tennessee	W. Virginia
Montana	Utah	Wyoming
North Carolina		

Current NDGPS Coverage

Federal Railroad Administration

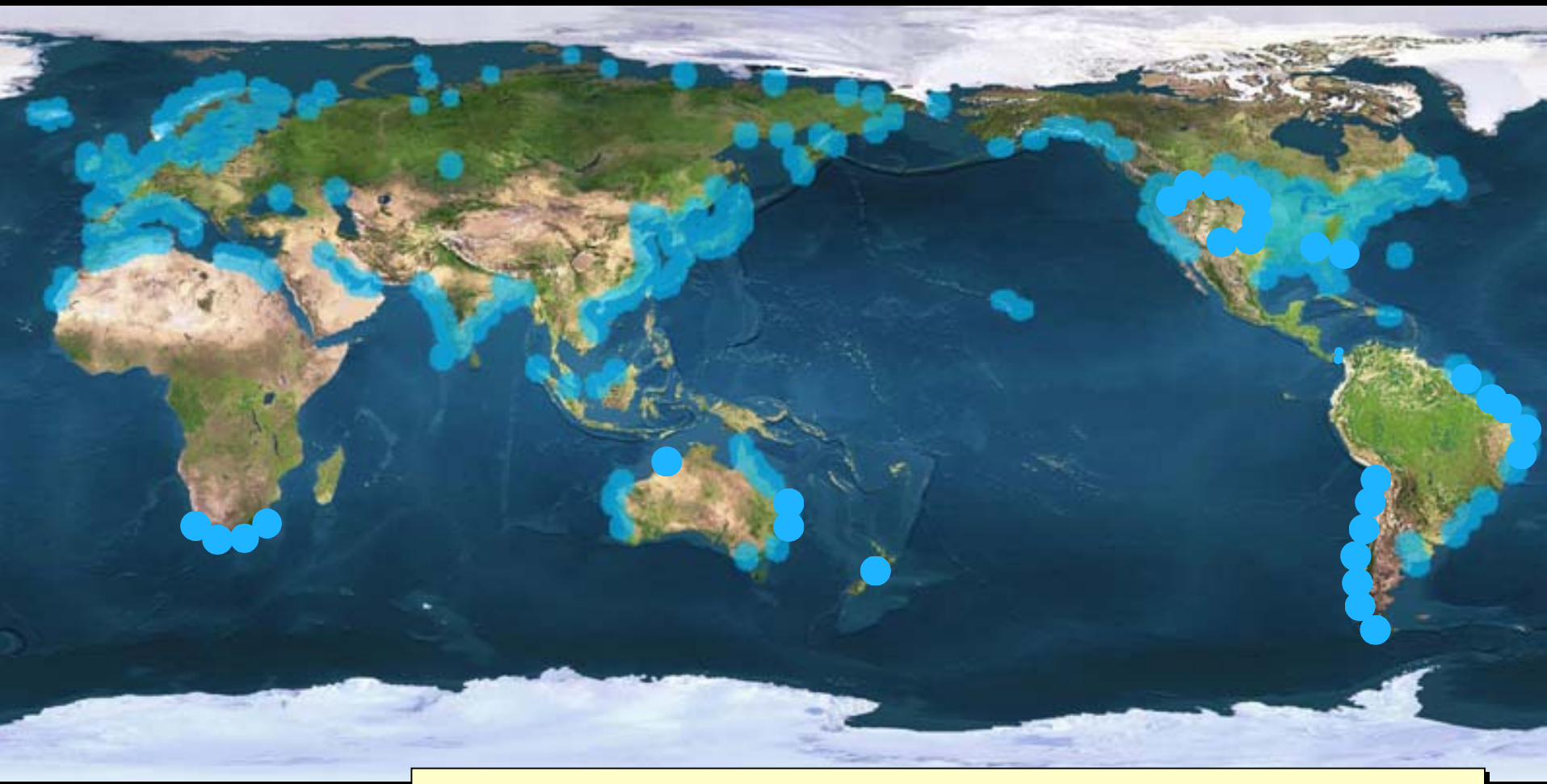


In the lower 48, approximately 92% has single coverage and 60% has dual coverage.

International Standard

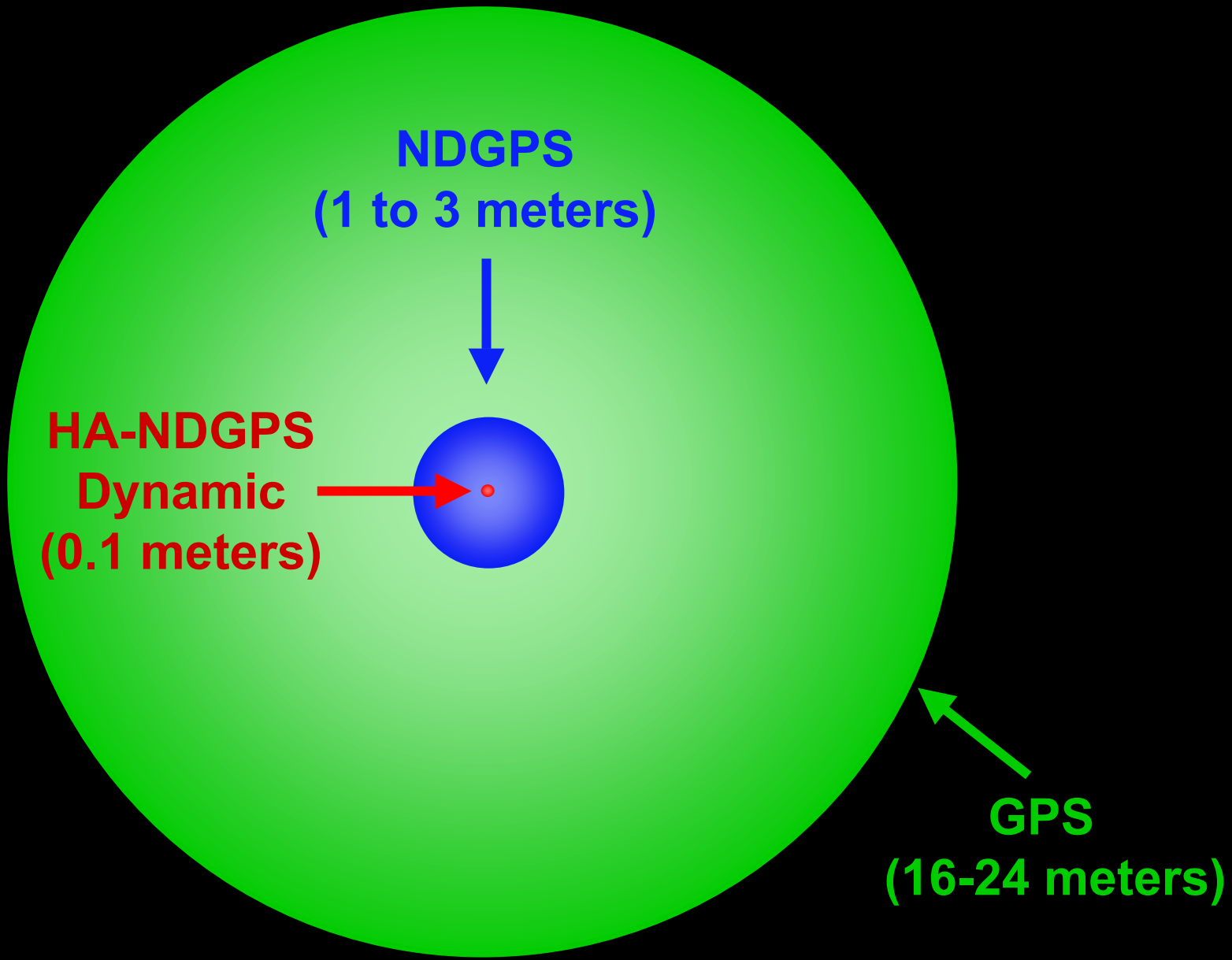
Federal Railroad Administration

- NDGPS is designed to an international, non-proprietary standard
  - Compliant with RTCM SC-104 and ITU-R M.823
  - Increases market for manufacturers
  - Enhances Global interoperability
- Signal is free to all users
- 47 other countries operate systems compatible to ours
- Resulting in a seamless international navigation system



Acceptance of the international standard is leading to a seamless worldwide service.

High Accuracy NDGPS



High Accuracy NDGPS

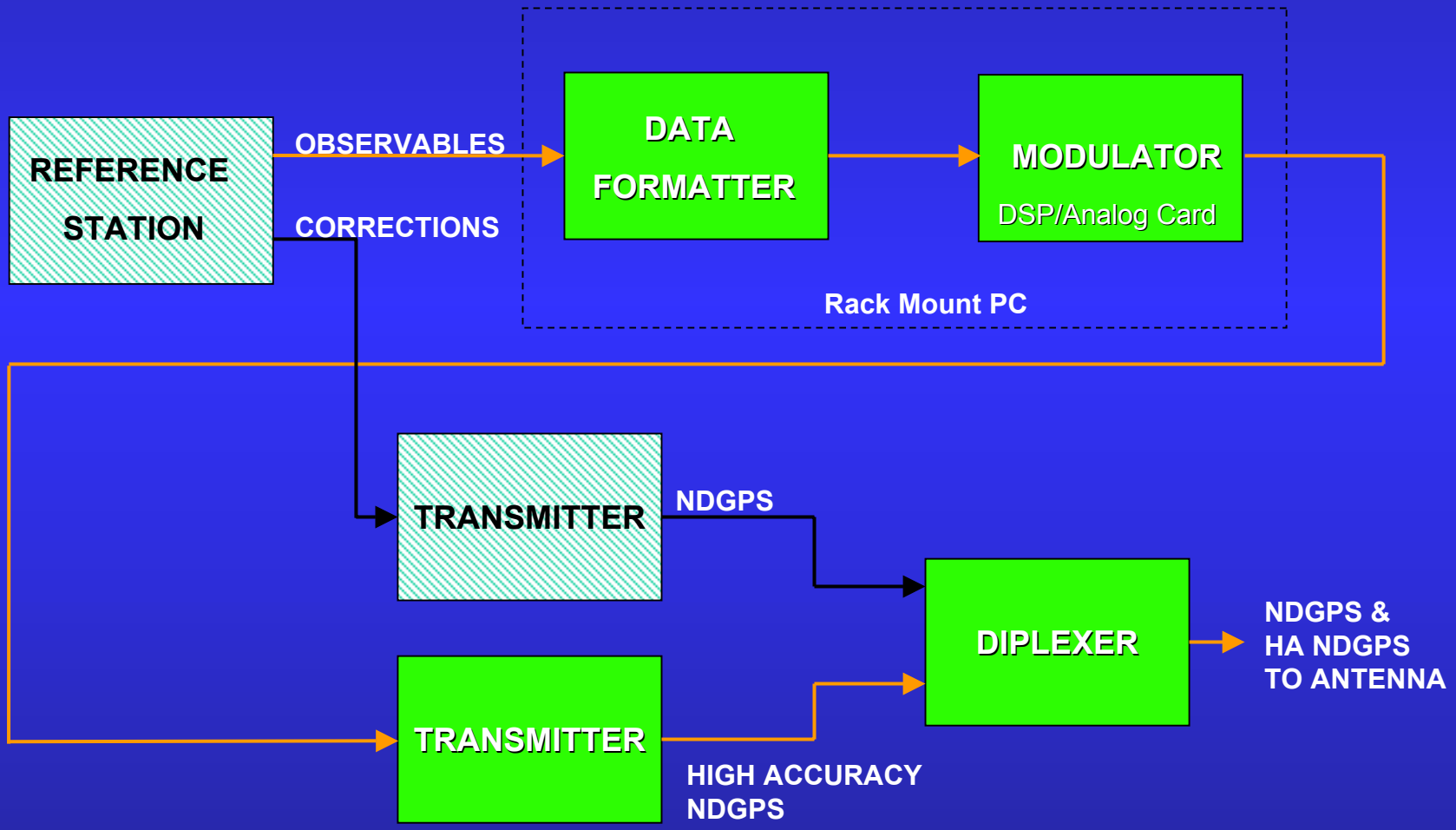
Program Objectives

Federal Railroad Administration

- Develop a nationwide 3-D dynamic positioning service that has an accuracy of less than 15 centimeter and time to alarm integrity of less than 2 seconds
- Coexist with existing NDGPS infrastructure
- Do not degrade existing NDGPS
- Minimize deployment costs

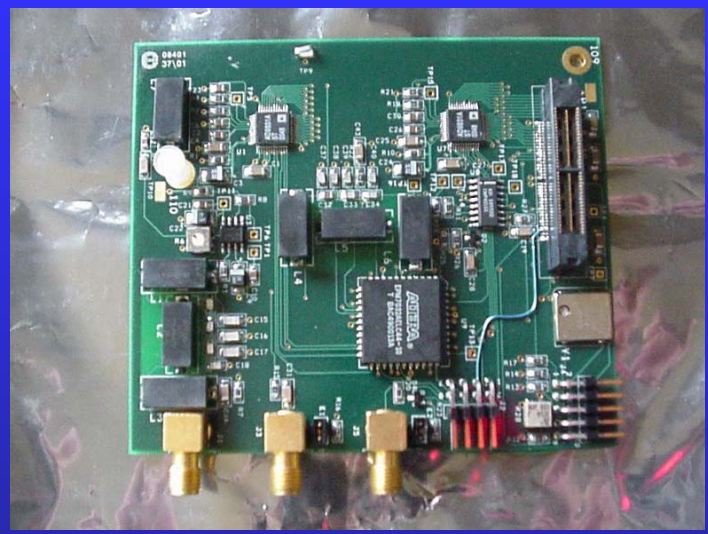
Broadcast Site Configuration

Federal Railroad Administration



Data Formatter And Modulator

Federal Railroad Administration



Diplexer

Permits the Broadcast of Two Signals on One Antenna

Federal Railroad Administration

Three of Five Sections

Single Panel

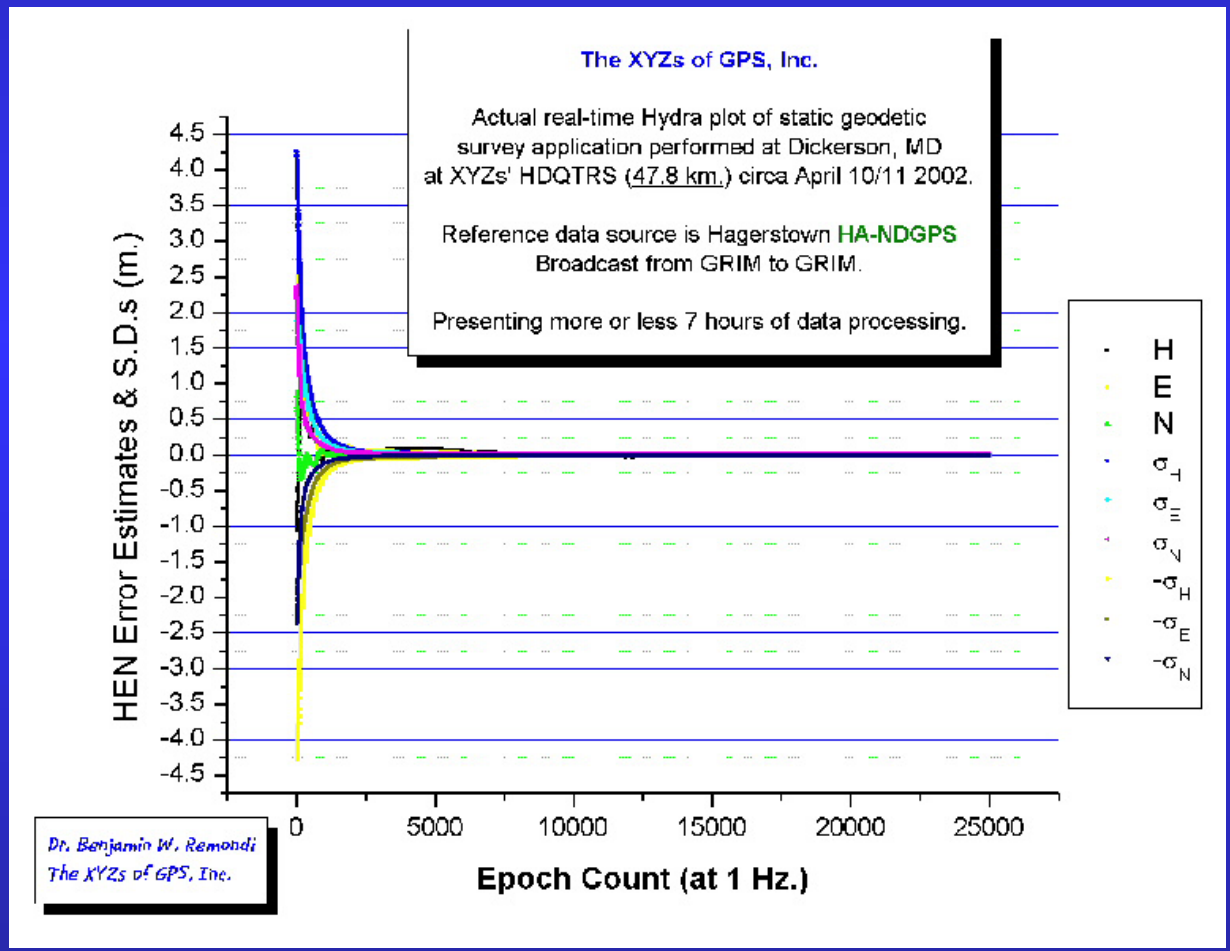
High Accuracy NDGPS

Federal Railroad Administration

10-15 centimeters at 150 miles on a dynamic platform (boat).

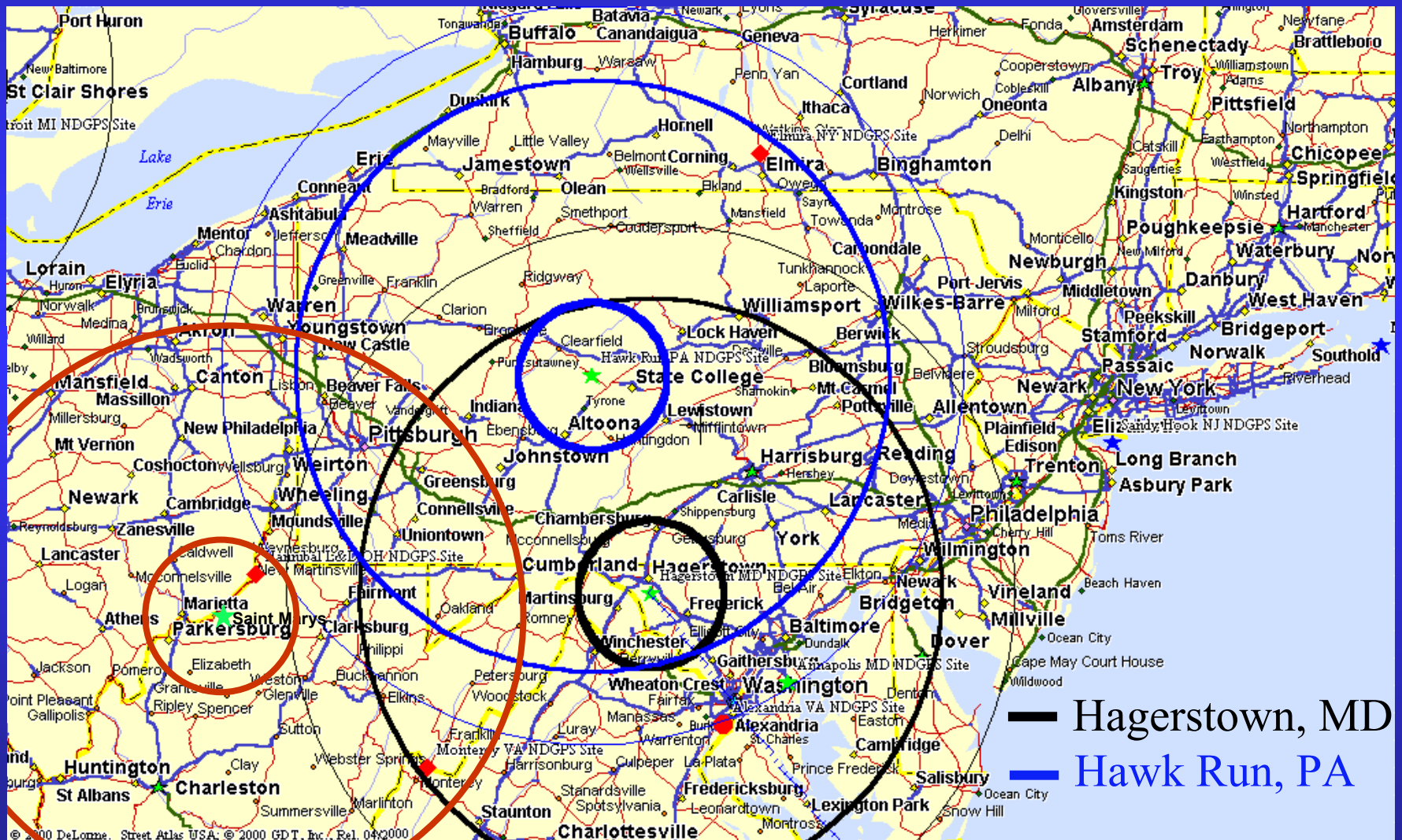
Accuracy Converges to About 2 cm in this Static Positioning Test after about 30 minutes

Federal Railroad Administration



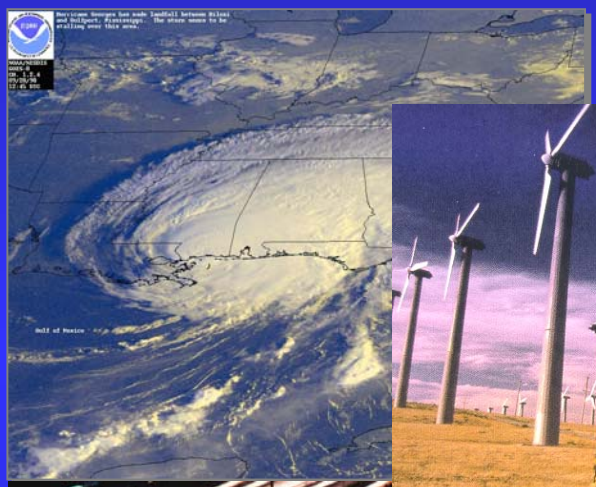
High Accuracy Nationwide Differential Global Positioning System (HA NDGPS) Coverage

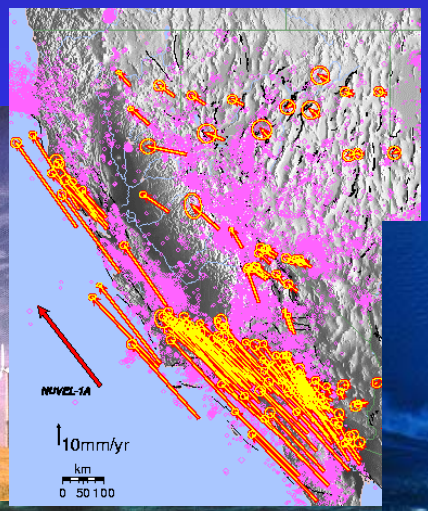
Federal Railroad Administration

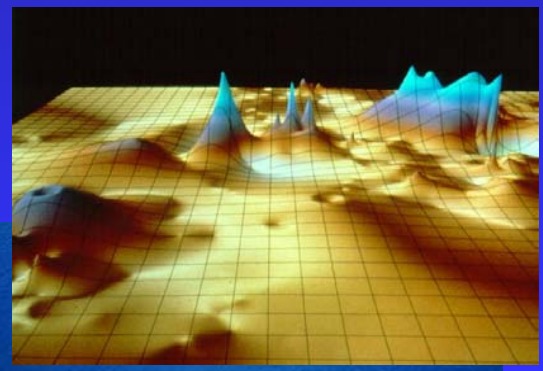


Nationwide Differential Global Positioning System (NDGPS) Applications

Federal Railroad Administration









Five Categories of NDGPS Applications

Categories of Applications	Provides
1. Original Code-Based NDGPS Applications	1 - 3 meters
Navigation, Precision Farming, Positive Train Control, Dredging, Buoy Positioning, Resource Management & GIS	
2. Real-Time High Accuracy NDGPS Apps	10-15 centimeters
Real-time Automated Surveying of Roads, Railroads & Harbors; Highway Lane Keeping; Machinery Control; & Auto-Docking of Ships	
3. Post-Processing NDGPS Applications	1 - 3 centimeters
Very Accurate Surveying, Mapping, Charting & Hydrography	
4. Stationary Scientific NDGPS Applications	2 - 3 millimeters
Plate Tectonics Monitoring & Earthquake Prediction	
5. Weather Forecasting Application	Water Vapor Info

NDGPS Use in *Positive Train Control*

Federal Railroad Administration

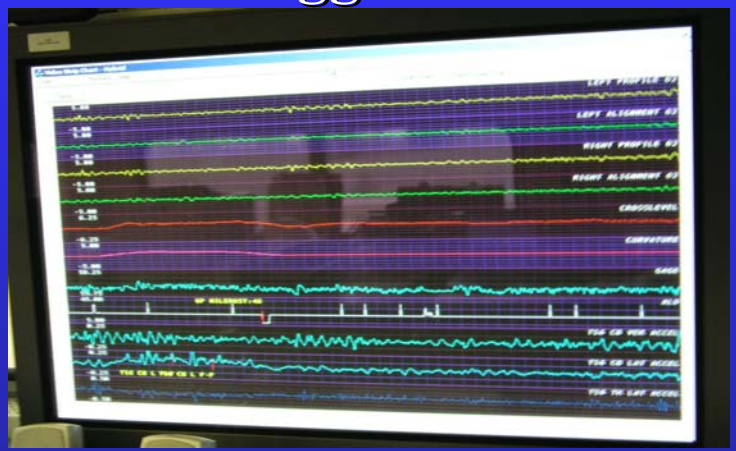
- **Provides Situational Awareness**
- **Prevents accidents, saving over $60 million per year**
- **Reduces fuel consumption by better pacing trains**

- **Increases rail line capacity through closer train spacing, thus reducing the need for additional capital investment in plant and equipment.**
- **Independent estimates indicate that NDGPS used in a full PTC system will save the railroads and shippers between 2 to 4 billion dollars per year.**

NDGPS Use on Track Geometry and R&D Test Cars

Federal Railroad Administration

- NDGPS is currently used on:
  - T-2000 Track Geometry Inspection Car
  - T-18 GRMS Car
  - T-16 R & D Car
  - Data tagged with Latitude,



High Accuracy NDGPS Use in Automated Rail Survey System

Federal Railroad Administration

- **Automated Rail Survey System consists of:**
  - High Accuracy NDGPS
  - GPS Heading Sensor
  - Gyro
  - Three Camera Image Capture System
  - Computer
- **Current Accuracy**
  - Track 0.21 meters
  - Wayside 1.4 meters

Working to improve track survey accuracy to less than 15 centimeters

Coast Guard Applications
Aids to Navigation

Federal Railroad Administration

- **Aids to Navigation**

  The Coast Guard created DGPS, in the mid 1980's, as a means to position buoys much more efficiently. In fact, the Coast Guard can position buoys in about one-third the time, using NDGPS compared to the time needed using the old sexton based system, resulting is significant savings in ship and crew time.

This new Juniper class buoy tender was designed with an autopilot system that uses NDGPS to navigate to an exact location and holds that location while the crew drops the buoy.

Coast Guard Applications
Maritime Navigation Safety

Federal Railroad Administration

Maritime Navigation Safety

- The Coast Guard also operates NDGPS to provide the accuracy, integrity and availability needed to meet the *harbor entrance and approach* requirements of the international Safety of Life at Sea (SOLAS) treaty.
- NDGPS is used by small recreational boat, fishing boats and large ships.

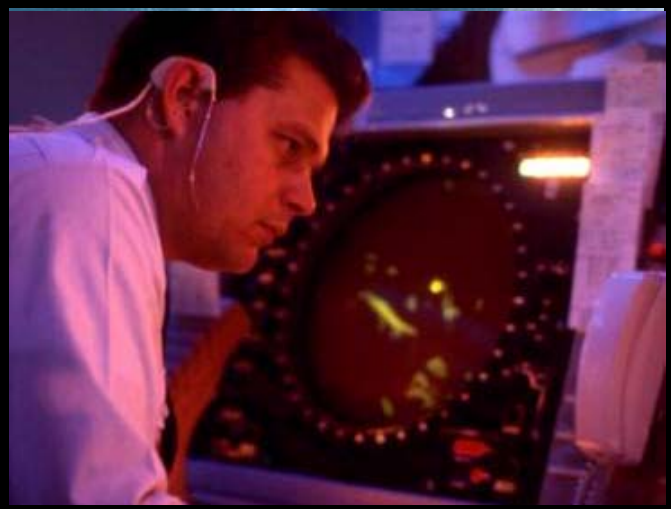
Coast Guard Applications
NDGPS Enables Other Navigation Safety Systems

Federal Railroad Administration

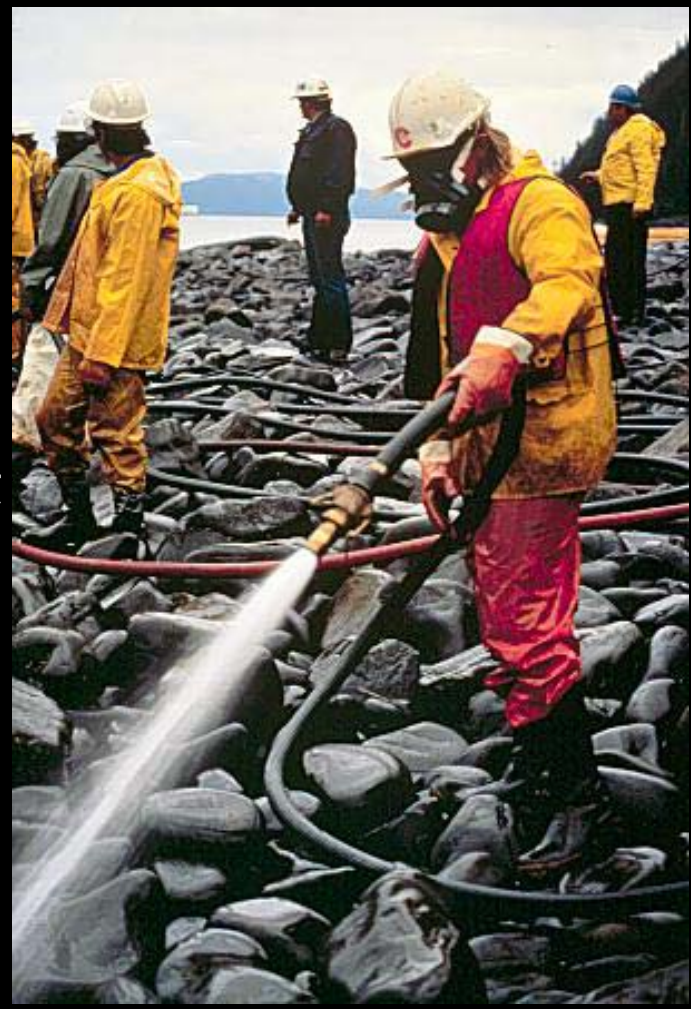
- The accurate NDGPS position of all ships in a harbor are displayed on **Vessel Traffic System**.
- NDGPS provides the most accurate position and speed information to **Automated Identification Systems (AIS)**. AIS displays these accurate positions on the radars of all other ships in the harbor and the VTS center, resulting in situational awareness.
- NDGPS enabled **Autopilots** keep ships in the channel regardless of the visibility or condition of the ships operator.

NDGPS Enabled Safety Systems Prevent Disasters Like Exxon Valdese

Federal Railroad Administration

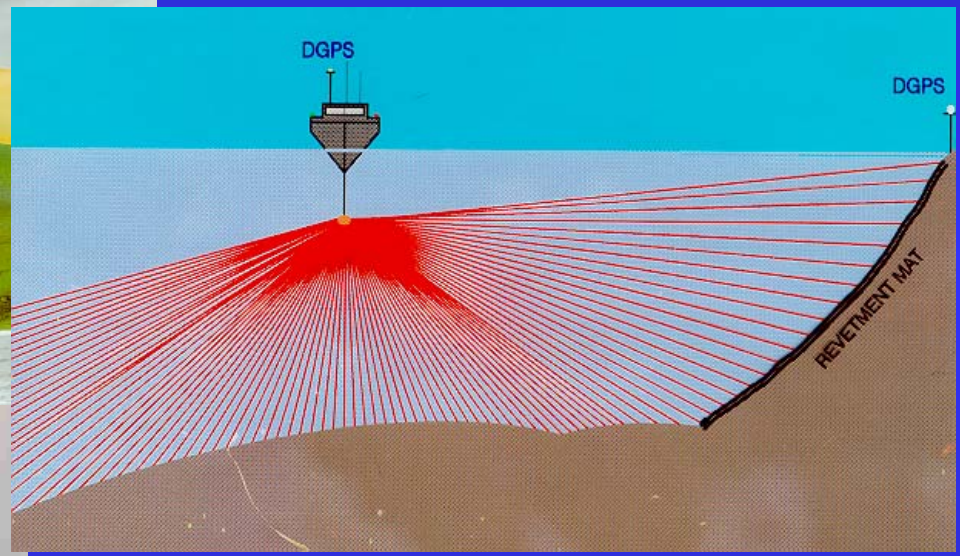


NDGPS Enables Technologies That Prevent Disasters Like Exxon Valdese



Army Corps of Engineers
NDGPS Applications

Federal Railroad Administration



Multibeam Hydrographic Surveying SB AdamsII (Norfolk District)

Army Corps of Engineers
NDGPS in Dredging

Federal Railroad Administration

Army Corps of Engineers needs 2 meter accuracy to position their dredging ships.

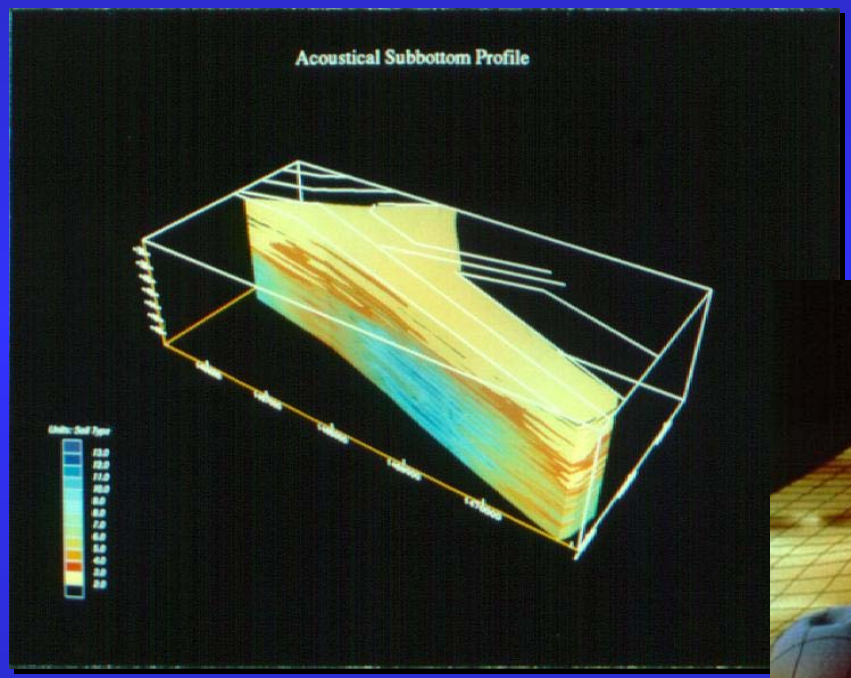
U.S. Army Corps of Engineers Uses of NDGPS

Federal Railroad Administration

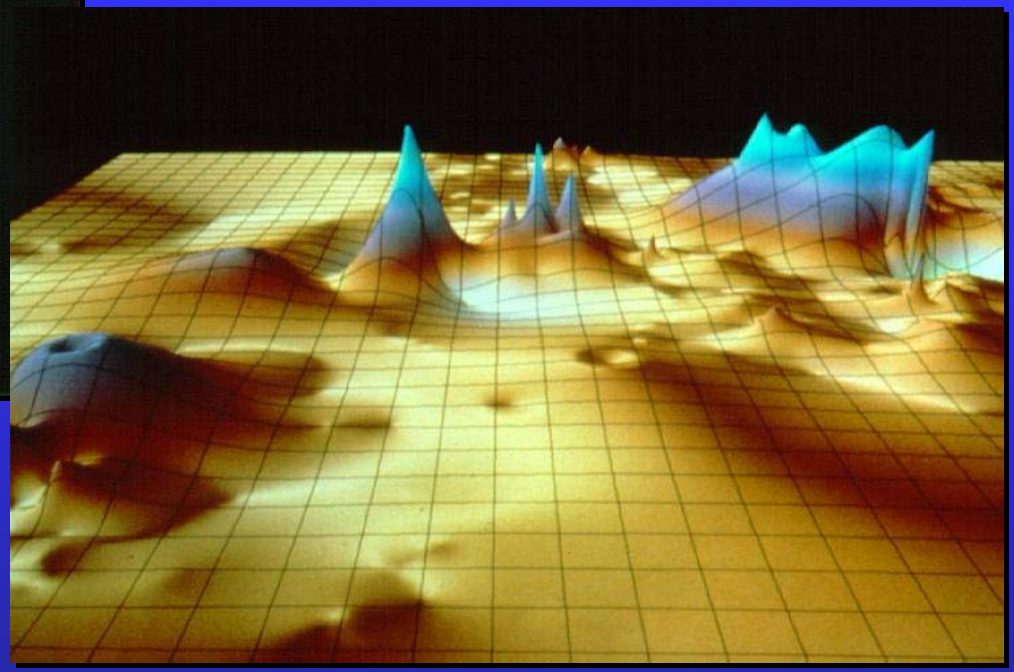
- **Facility Mapping (Site Plans & GIS)**
  - Training Range Plans
  - Airfield obstruction mapping
  - Training range mapping/location
  - Utility Location & As-Builts
  - Environmental Mapping
- **Flood Control Projects**
  - Floodplain Mapping
  - Soil/Geology Classification Maps
  - Cultural/Economic Classifications
  - Land Utilization Mapping
  - Wetland/Vegetation Delineation
  - Geotoxic Data Mapping/Modeling
- **Emergency Operations**
  - Personnel location
  - Facility location
- **Real Estate**
  - General Location Maps
- **Navigation Projects**
  - Dredge Control:
    - Horizontal position
    - Disposal area monitoring
  - Hydrographic Survey Control:
    - Project condition
    - Measurement & payment
  - General Vessel Navigation
  - Shoreline Mapping
- **Hydraulic & Hydrology Studies**
  - Horizontal reference
- **Geotechnical Investigations**
  - Boring location (horizontal)
- **Construction**
  - Material placement (horizontal)
- **HTRW Site Control & Mapping**
  - Geotoxic Data Mapping/Modeling

Hydrographic Surveys and Aerial Mapping

Federal Railroad Administration

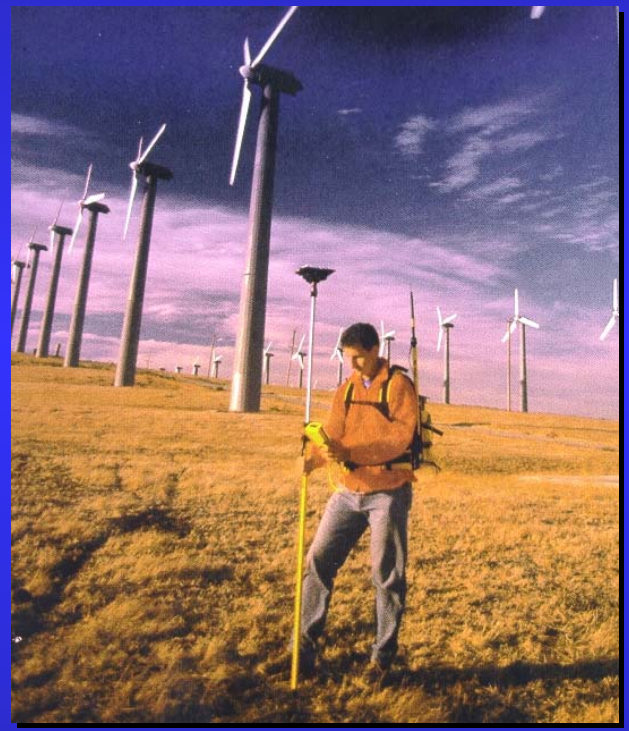


NDGPS is used in Hydrographic Surveying and Aerial Mapping.



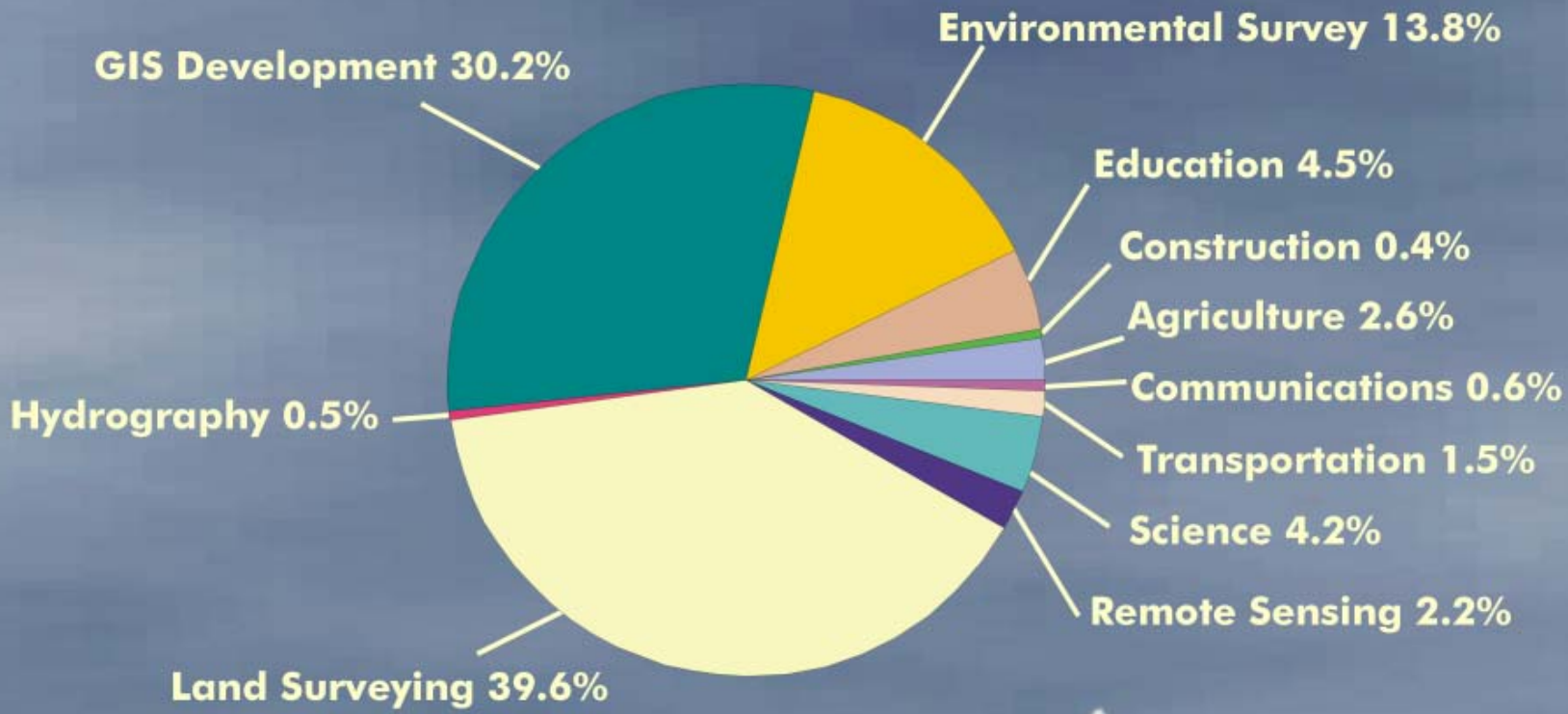
NDGPS use in Surveying

Federal Railroad Administration



GPS has revolutionized the surveying industry. NDGPS provides survey grade accuracy when used in post processing applications.

CORS Applications



5,646
Survey responses
Fall 1999

Precision Agriculture

Federal Railroad Administration

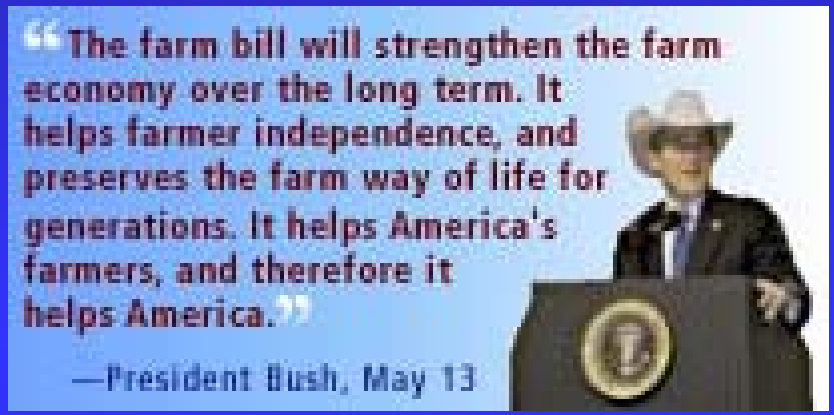
NDGPS used in Precision Farming saves $5 to $14 per acre.

- **NDGPS is used to:**
  - **Map Soil quality**
  - **Reduce use of pesticides and fertilizers**
  - **Monitor crop yield**

Resulting in 3 to 5 billion dollars per year in savings

U.S. Department of Agriculture

Federal Railroad Administration



In order to meet the technical assistance requirements of the new farm bill, USDA NRCS is signing up 5500 Technical Service Providers who will also use NDGPS to provide assistance to USDA customers.

The USDA Service Center Agencies (NRCS, FSA, RD) have spent $8M & purchased over 6,000 NDGPS receivers. There is still a requirement for an additional 1700+ NDGPS receivers.

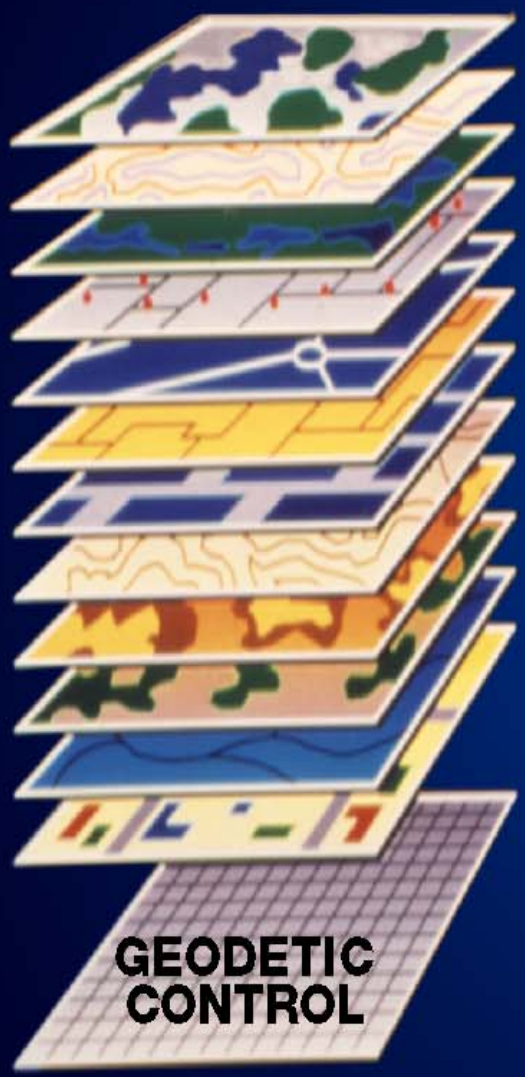
Currently, Farmers, Ranchers, Land Managers, AG Service Providers, Ag researchers, and AG manufactures are using NDGPS. That number of AG sector NDGPS users is expected to grow exponentially.

Agriculture
Safety of Life Issues

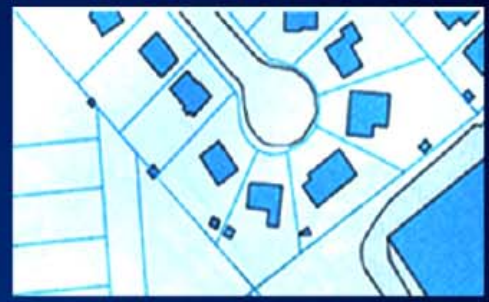
Federal Railroad Administration

Fire fighters use NDGPS for navigation and to inform Fire Command of their position.

Geographic Information Systems (GIS)



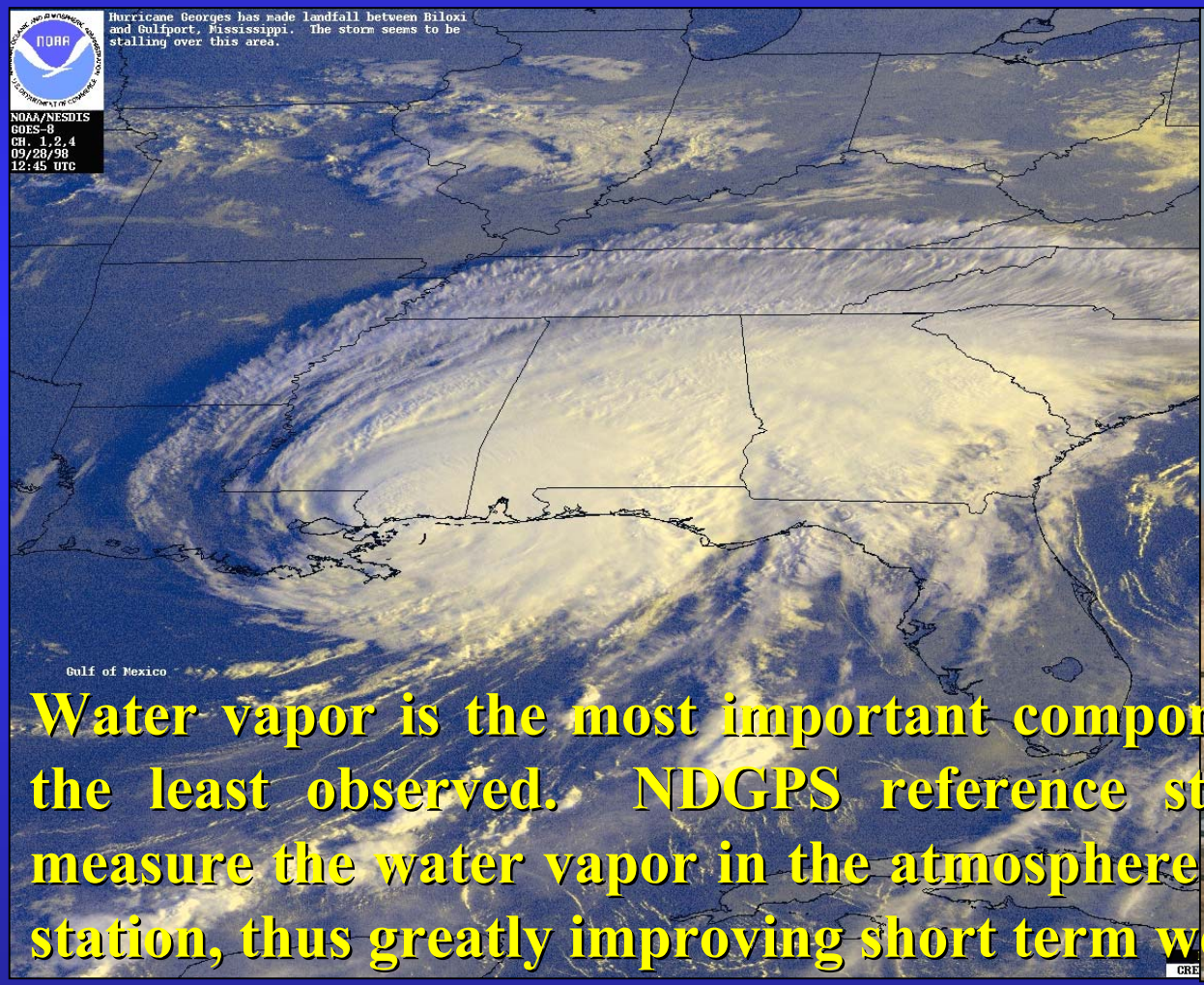
Wards and Precincts
Demographics
Structures
Water Utilities
Sewerage
Electrical Utilities
Roads
Boundaries
Land Use
Hydrology
Soils
Topography



NOAA's Forecast Systems Lab

Uses NDGPS to continuously Measure Water Vapor

Federal Railroad Administration

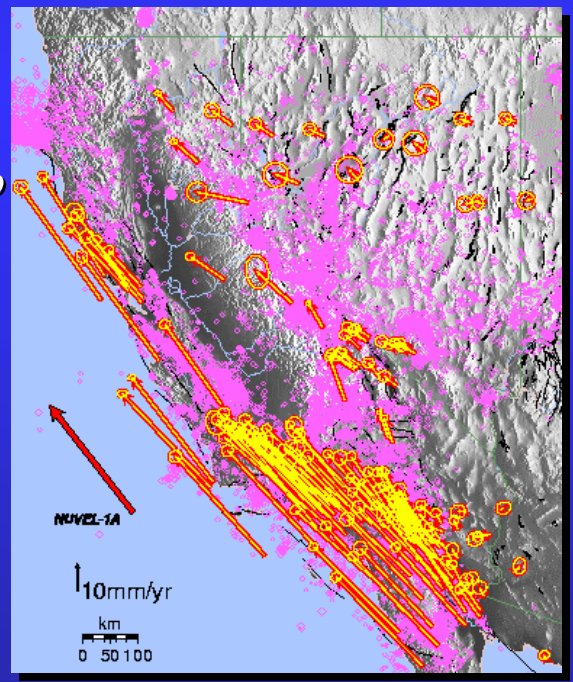


Water vapor is the most important component of weather and the least observed. NDGPS reference stations continuously measure the water vapor in the atmosphere above the reference station, thus greatly improving short term weather forecasts.

University NAVSTAR Consortium (UNAVCO)

Federal Railroad Administration

- UNAVCO is a non-profit organization that promotes high-precision geodetic & strain techniques using GPS.
- Funded by NSF and NASA.
- Uses dual-frequency GPS receivers to measure Plate Rigidity, Plate Movement, Plate Deformation, Plate Boundary Zones to the millimeter level.
- NDGPS program has installed high stability antenna mounts & choke ring antennas at several sites to meet UNAVCO needs.



Success Through Teamwork

Awarded the Secretary of Transportations Team Award in 1998

Awarded the Vice President's Hammer Award for reinventing government in 1999

Letters of Support
For the NDGPS Program

Federal Railroad Administration

- **When the government was considering developing NDGPS, it received over a score of support letters:**

From	To
Users	President of the United States
Industry	Secretary of Transportation
Governors	Director of OMB
Senators	Senate Appropriations
Congresspersons	House Appropriations

- **These letters highlighted the importance of the NDGPS program and the benefits in various applications.**

Appropriations History

Federal Railroad Administration

- FY1998 -- $ 2.4M (in Coast Guard appropriation)
- FY1999 -- $ 7.2M Requested in FRA budget
  $ 5.5M (in Coast Guard appropriation)
- FY2000 -- $10.4M Requested in FRA budget
  $ 5.0M (in FHWA appropriation)
- FY2001 -- $18.7M Requested in FRA budget
  $ 6.0M (in FAA appropriation)

While that support got the program started, it did not ensure adequate funding.

Appropriations History
Continued

Federal Railroad Administration

- FY2002 -- $20.5M Requested in FRA budget
  $ 6.0M (in FHWA appropriation)
- FY2003 -- $32.1M Requested in FRA budget
  $ 6.0M (in FAA's appropriation)
- FY2004 -- $27.0M Requested in FRA budget
  $ 5.8M (in FRA's appropriation)

At current funding levels the NDGPS program is not executable.

Executive Steering Council
Reconvenes to Address Funding Problem

Federal Railroad Administration

- **Despite the enormous benefits and significant level of partnership among federal and state agencies, the program still lacks adequate funding.**
- **The Secretary of Transportation reconvened the Interagency NDGPS Executive Steering Council, consisting of senior management from several departments – DOT, DHS, DOI, DOC, USDA, USCG, ACOE, NWS, BOC and OMB – to address the funding shortfall and to consider whether or not to implement High Accuracy NDGPS.**

Funding Period

Four year implementation

All values in millions of dollars

Federal Railroad Administration

	Total Needed	FY06	FY07	FY08	FY09	FY10 & Beyond
CONUS	$20.0	$5.0	$5.0	$5.0	$5.0	
AK	$27.0	$6.75	$6.75	$6.75	$6.75	
High Accuracy	$25.0	$6.25	$6.25	$6.25	$6.25	
Total Construction	$72.0	$18.0	$18.0	$18.0	$18.0	
Operations & Maintenance	$30.4	7.6	7.6	7.6	7.6	9.2
Total		$25.7	$25.7	$25.7	$25.7	$9.2

NDGPS Executive Steering Council
May 14, 2004

Federal Railroad Administration

- **Interagency NDGPS Executive Steering Council Approved:**
  - **Dual coverage in lower 48**
  - **15 Sites in Alaska**
  - **High Accuracy NDGPS modification to all 130 sites**
  - **Four year completion schedule**
- **FRA requested $25.7M in FY06 to support 4 yr schedule**
- **OMB approved $20.0M in the President's FY06 budget.**
- **Still has to pass the House and the Senate. Either could cut, approve or even plus-up the President's request.**
- **We need strong support from the user community, DOT, and OMB to ensure funding doesn't get cut.**

Nationwide Differential Global Positioning System (NDGPS)

Federal Railroad Administration

Len Allen

Program Manager

Intelligent Railroad Systems

Office of Research & Development

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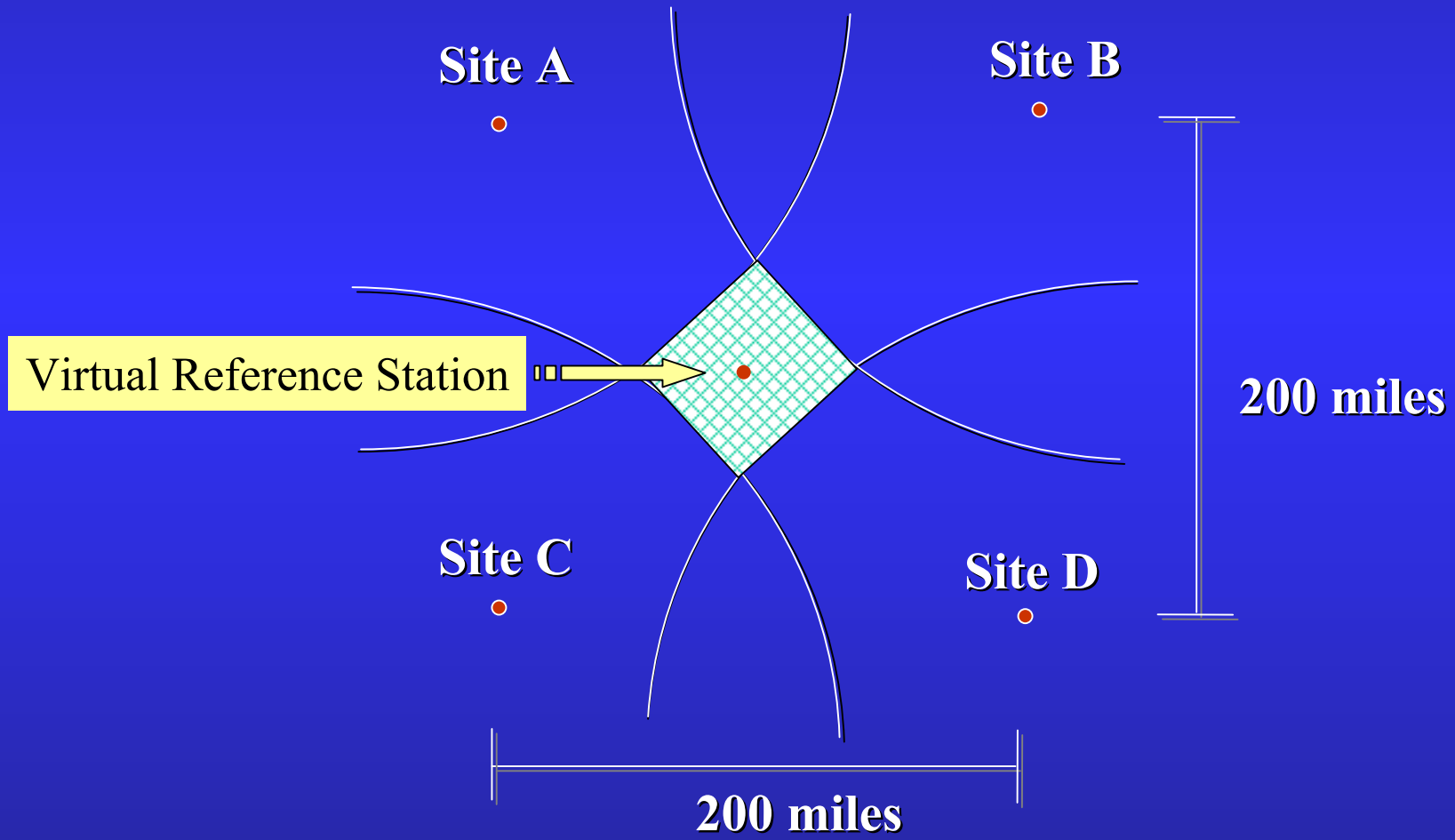
Backup Slides

Broadcast Ranges

Virtual Reference Station

Federal Railroad Administration



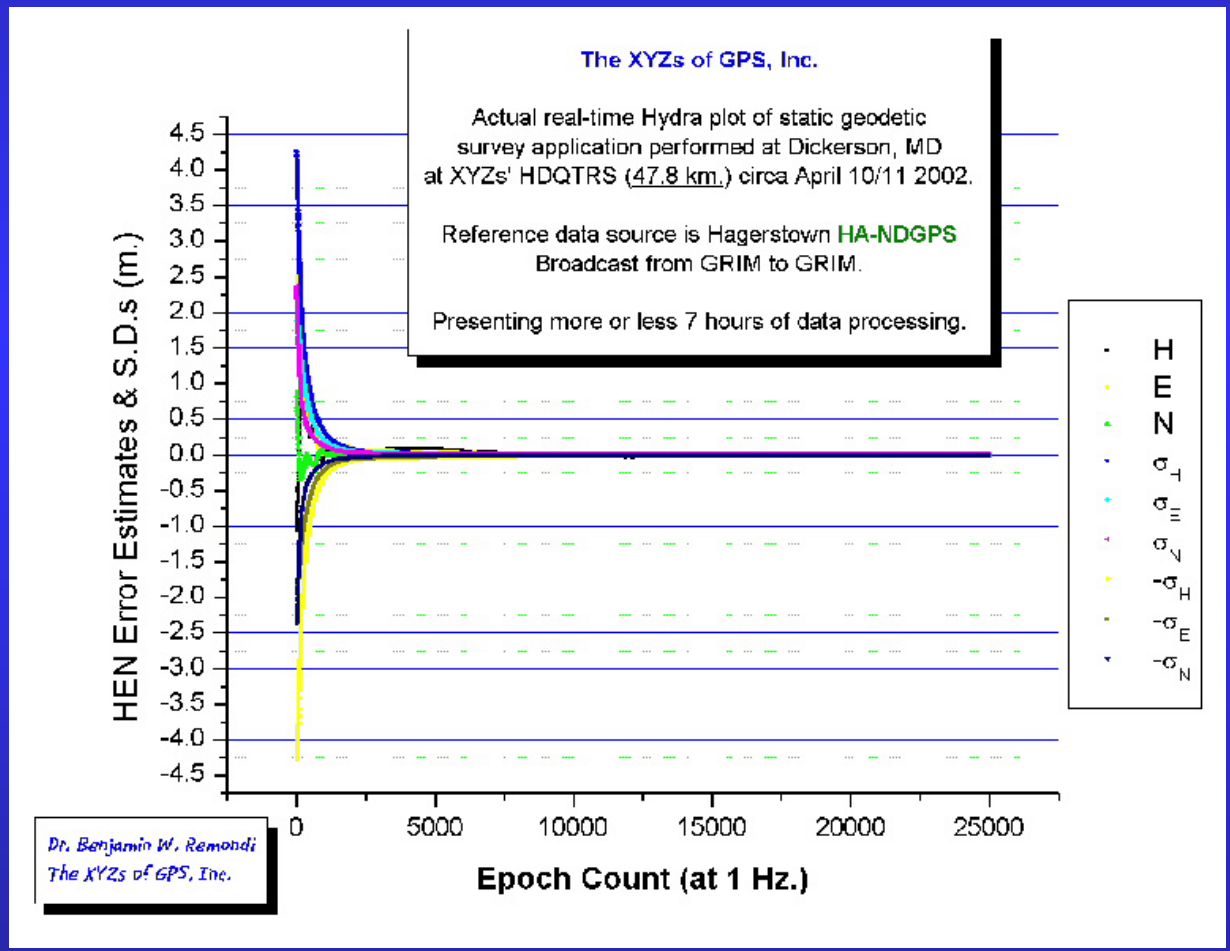
Policy & Implementation Team
Report and Recommendation

Federal Railroad Administration

- **Recommended expansion of the Coast Guard's DGPS**
  - Can be easily expanded
  - Signal is not blocked by trees, hills and buildings
  - Meets most land and maritime navigation needs
  - Meets surveying needs when post processing techniques are used
  - Can be modified to provide high accuracy (10 to 15cm) in real time for surveying and land navigation needs
  - Enormous benefits in a wide array of applications – navigation, precision farming, surveying, positive train control and GIS
  - Implementation costs are low
  - Partnership potential with many state and federal agencies
- **Executive Steering Group unanimously decided to expand the Coast Guard DGPS into a nationwide service**

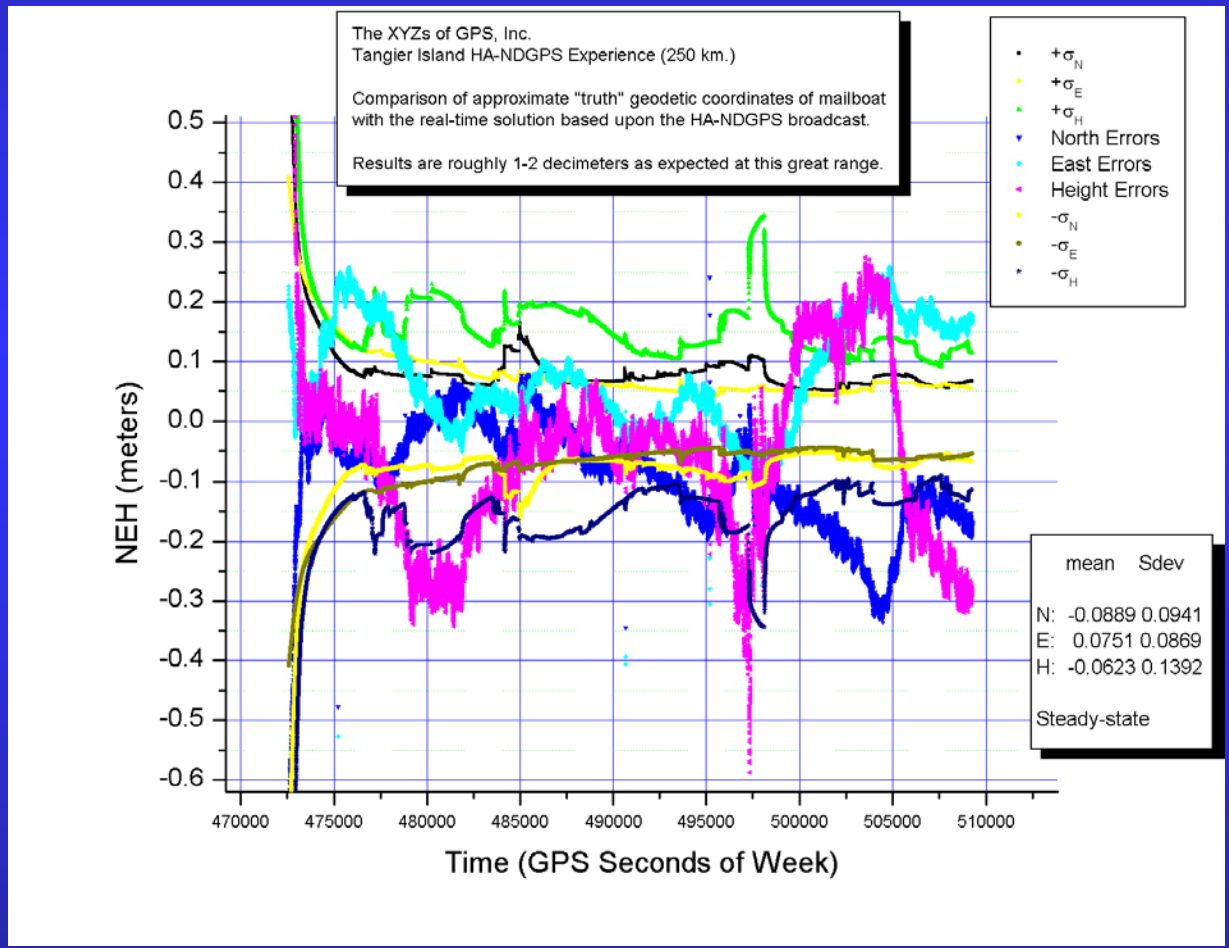
Static Positioning At 50 km

Federal Railroad Administration



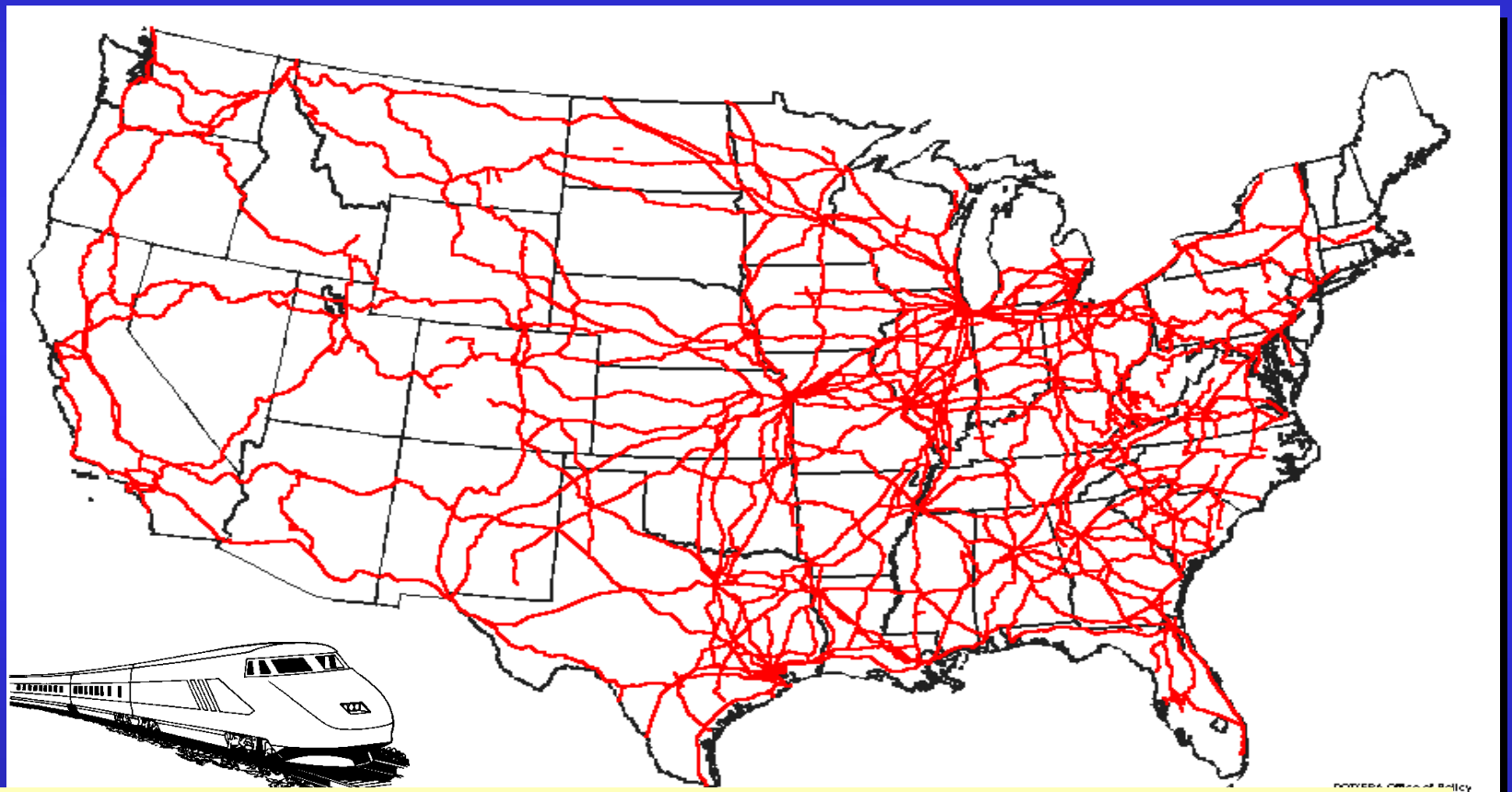
Long Range (250 km) Single Baseline Test

Federal Railroad Administration



Major Railroad Lines

Federal Railroad Administration



A ubiquitous service with a high degree of accuracy & integrity is needed to improve railroad safety, efficiency & security.

Precision Agriculture Applications

Federal Railroad Administration

Funding Needed to Complete

Federal Railroad Administration

$20M Site Construction in Contiguous 48

$27M Site Construction in Alaska

$25M High Accuracy NDGPS for all 130 Sites

$72M Total Future Construction Costs

$7.2 – 9.2M Total Annual Operations & Maintenance

- $7.2M in 2006
- $9.2M when the system is complete

The Broadcast

Federal Railroad Administration

- **Broadcast Code and Carrier Phase Data**
  - Capability to broadcast all observables (L1, L2C, L5, others) contained in less than 1000 bits in the compact format
  - Data rates up to 1 kilobit per second
  - Initially L1 and L2-P(Y) observables were broadcast
- **Utilize an Advanced Broadcast Link**
  - Data synchronized to GPS time
  - Carrier calibrated with GPS to sub-hertz levels
  - Spectrally efficient modulation (raised cosine MSK)
  - One second data updates in compact mode